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The role of renewables in increasing Turkey's self-sufficiency in electrical energy

Mustafa Ozcan

Electricity and Electronics Department, Şişli Technical School, Şişli, 34381 İstanbul, Turkey

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ABSTRACT

Imported fossil fuels dominate Turkey's total primary energy supply and this situation poses a significant barrier to the country's self-sufficiency. However, Turkey can increase its self-sufficiency by tapping into its rich but under-utilized potential of renewable energy sources (RES). Looking into the data from the period between 1980 and 2014, this study scrutinizes Turkey's self-sufficiency in total primary energy generation and electricity generation and changes that could occur depending on energy policy goals. Also, this study discusses the implications of the increasing utilization of coal reserves in relation to the escalating concerns about climate change. Given the important role of RES in ensuring self-sufficiency, Turkey's rate of utilization of its RES and the possibility of its realizing the Vision 2023 energy targets have been evaluated. The utilization and attainment rates based on the country's 2023 energy targets for all RES reveal that Turkey is far behind the intended progress rate regarding the utilization of RES, except for hydro and geothermal. Our analysis shows that Turkey's self-sufficiency in total primary energy generation and in electricity generation has been deteriorating in the last decades. The rate of self-sufficiency was %54.42 in 1980. However, by 2014 this rate had gone down to %25.05. Turkey's self-sufficiency rate in electricity generation dropped from 77% in 1980 to 37% in 2014. The main reasons for this change are the high energy demand, increasing reliance on imported natural gas and hard coal, and low utilization of RES. Therefore, in order to achieve Vision 2023 RES targets and ensure self-sufficiency in the long run, we suggest the introduction of new energy policy instruments for RES.

1. Introduction

Turkey has experienced a considerable surge in energy demand in recent years, which has had a major impact on its energy supply [1]. As a consequence, the country has become increasingly dependent on energy imports, to the extent that currently about 75% of the total primary energy supply (TPES) is being met by energy imported from other countries [1], natural gas and oil having the highest share in energy imports. In 2014, it had to import nearly 92% of its oil and 99% of its natural gas. Turkey's hard coal import volume has also grown in recent years. The country imported nearly 95% of the hard coal it used in 2014 [1]. As a result, energy security has been a key priority of Turkey's energy policy.

Turkey's total electricity demand has been increasing rapidly. The country's total net electricity generation significantly increased from 23.275 TWh in 1980–250.436 TWh in 2014 [2,3], while the Gross Domestic Product (GDP) increased from 67.46 billions of dollars to 800.11 billions of dollars within the same time period [4]. When the figures concerning Turkey's total net electricity consumption between 1980 and 2014 are analysed, it can be seen that there has been a steady increase in consumption, except for some short periods of decrease in the aftermath of economic crises [3,5,6]. The total net electricity consumption was 554 kwh per capita in 1980, which increased to 3288 kWh per capita in 2014 [3,6–8].

Electricity from hydroelectric power plants (HPPs) accounts for a significant share of Turkey's total energy generation from renewable energy sources (RES). However, at present, most of Turkey's electricity generation comes from fossil fuel power plants (FFPPs). The share of electricity generation from FFPP has increased from 51% in 1980 to 79% in 2014 [2,3]. Although Turkey does not currently generate any electricity from nuclear power plants (NPPs), the government has been advocating the construction of NPP to diversify Turkey's electricity supply portfolio. In May 2010, an intergovernmental agreement was signed between the Russian Federation and the Republic of Turkey, and the construction process of the first NPP of Turkey commenced in the Akkuyu district of Mersin province. The construction of the marine hydro-technic structure of the plant started in 2015. However, it should be noted that the Akkuyu NPP, consisting of four power units with a

E-mail address: ozcanm2000@gmail.com.
URL: http://www.mustafa-ozcan.com.

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total capacity of 4800 MW, has not yet been granted a production license.

Turkey has a large potential for RES [9–14]. The country's realizable renewable energy potential is equal to 13% of EU-27's total potential, and in this respect Turkey ranks fifth after Germany, France, Spain and the UK. In numbers, Turkey's total electricity generation potential from RES is 240,165 GWh/yr for 138,000 MW economic potential. It has several different types of RES: 144,000 GWh/yr hydro (for 36,000 MW), 14,665 GWh/yr geothermal (for 2000 MW), 60,000 GWh/yr wind (for 48,000 MW), 14,000 GWh/yr biomass (for 2000 MW), and 7500 GWh/yr solar (for 50,000 MW) renewable energy potential [15,16]. Studies on Turkey's RES document the level of RES potential for various RES types and emphasize their important role in finding a solution to the current economic, environmental and energy problems of Turkey [10,13,14,17–22].

There is a global trend of using more RES. Globally, increasing greenhouse gas emissions, the instability of fossil fuels prices, and rising concerns over energy security encouraged many countries to increase their investment in RES [21]. Maturity in developments of renewable energy technologies and decrease in the costs of RES make these sources more acceptable worldwide. Large initial investments of some RES had an adverse effect on market entry. However, in recent years, the costs of renewable technologies have been following a downward trend. There is a recent cost reduction trend for RES technologies in the world, and it is anticipated that solar and wind power technologies will see further decline by 2025 [23]. When the external cost of electricity generation is included while calculating electricity generation costs, electricity generation from wind and solar power is found to be cheaper than generation from coal in Turkey and the costs of RES continue to fall [24].

RES incentive mechanisms are incorporated into markets to compensate for cost-related barriers and to increase RES deployment rate. Financial incentives are important policy instruments to encourage RES investors. By deploying these incentive mechanisms, governments indirectly aim to decrease CO_2 emissions and improve energy supply security [25]. In Turkey, the level of financial incentives and appropriate credit opportunities for domestic entrepreneurs is lower than some European countries [13].

Coal is still a widely used energy source worldwide [26], and it is the main domestic fossil energy source of Turkey. A large majority of Turkey's coal reserves consist of lignite. However, the lignite found in the country has low calorific value and high amount of humidity, sulphur and ash. Turkey has 1.5% of the world's coal reserves, while its lignite reserves represent 6% of the global lignite deposits [27]. As the major domestic energy source of Turkey, lignite constituted about 12% of the TPES in 1980 and in 2014 [1]. The second most important coal type is hard coal, which is followed by other types of coal found in Turkey's much smaller reserves [27]. Energy sector's high share in GHG emissions, which have been steadily increasing, is an alarming global environmental issue and therefore requires that Turkey's coal reserves be handled in the most efficient and environmentally friendly way possible. Because of its physical and chemical properties, lignite needs special attention to ensure its utilization in an efficient and environmentally friendly manner [21,22,28].

Governments support coal industry by providing subsidies to coal. Global fossil fuel subsidies amounted to US$ 548 billion in 2013. The amount of fossil fuel subsidies were over four-times the value of RES subsidies in the same year. Turkey's coal subsidies amounted up to around US$ 300 million in 2013. Through a simple elimination of the coal subsidization scheme, Turkey can reduce its aggregate GHG emissions by as much as 5% without a significant loss in its GDP. Coal subsidy phase-out would decrease CO_2 emissions and fiscal burden, and it offers prospects for generating green jobs and green energy [26]. It should also be pointed out that a considerable body of literature emphasizes the harmful environmental impact of coal utilization and recommends that coal be replaced by RES as a more efficient and effective solution to reduce the GHG emissions of Turkey [17–19,27].

Turkey does not have enough indigenous natural gas and oil reserves to supply its increasing fossil fuel demand. Turkey's dependence on energy imports places a big burden on its foreign trade deficit. This dependency, on oil and gas in particular, forms the backdrop for policy concerns related to energy supply security. Energy supply security is defined as “the uninterrupted availability of energy sources at an affordable price” [29]. To ensure energy supply security, the gap between demand and supply should be reduced; energy efficiency indicators should be improved; the optimal energy mix should be achieved; and vulnerability to energy price fluctuations should be reduced [9]. Energy diversification can be achieved through the utilization of both RES and non-RES as well as multiple carriers. RES are an important focus in energy diversification due to the scarcity associated with non-RES besides other problems associated with non-renewable energy sources mentioned above.

Reaching energy self-sufficiency and sustainability is one of the most important policy instruments to ensure energy supply security [30,31]. In view of environmental and economic impacts of coal utilization, RES appears to be one of the most efficient and effective solutions for becoming more energy self-sufficient than ever before.

Energy self-sufficiency rate is defined as the ratio between domestic production and TPES in a given year. In 2014, the level of self-sufficiency in OECD countries was estimated as 78%, and for the EU countries it was 47% on average [32,33]. Better utilization of RES and domestic sources could ensure self-sufficiency in the energy sector. Fossil fuels are finite sources and can irreparably harm the environment. For these reasons, the utilization of RES in the energy sector is one of the best methods to increase energy self-sufficiency rates and to achieve the rapid emission reductions that need to be set as a priority goal. Deployment of RES reduces GHG emissions, increases energy self-sufficiency, and consequently increases energy supply security [17,18,30]. Achieving energy self-sufficiency based on renewables would also enable significant reductions in environmental pollution [17,34–36]. As a result of the developments in the use of RES in meeting the rising worldwide energy demand, many successful projects have been carried out in order to achieve energy self-sufficiency through RES [37,38].

In this study, Turkey's self-sufficiency in TPES and in electricity generation has been analysed for the period between 1980 and 2014. The increasing utilization of coal, which is the main indigenous fossil fuel of Turkey, has been discussed against the backdrop of rising concerns about climate change. Considering the negative environmental effects of coal and important role of RES in ensuring self-sufficiency in energy, more attention has been paid to RES as Turkey is a rich country in terms of the variety and potential of RES.

Utilization and attainment rates of RES in Turkey with respect to achieving self-sufficiency in electrical energy generation have been determined. Having more information on the actual and potential shares of RES in TPES and electricity generation will help Turkey set more appropriate energy policies.

The structure of this article is as follows: Section 2 analyzes TPES by source types over the period of 1980–2014. Also, future TPES scenarios with respect to Turkey's 2023 energy vision are given in this section. In Section 3, utilization rates of primary energy sources for electricity generation are defined. In Section 4, changes in GHG emissions and the role of coal in increasing GHG emissions are discussed. In Section 5, the utilization rates of RES in Turkey and attainments regarding the 2023 energy policy targets are analysed. In Section 6, Turkey's energy self-sufficiency and self-sufficiency in electricity generation rates between 1980 and 2014 are calculated, and this is followed by an analysis of the economic implications of importing energy. Finally, in Section 7, some general conclusions are drawn and several recommendations are made.

2. Source – based analysis of total primary energy supply

Turkey's TPES in 1980 was 31.973 million tonnes of oil equivalent (MTOE), and with 51% oil had the biggest share in this figure. RES accounted for only 25% of TPES. Coal accounted for 21% of TPES, and hydro constituted the remaining 3%. Natural gas accounted for only 0.021 MTOE in supply and was used exclusively for industrial consumption. There was no contribution from nuclear in TPES. Other than hydro, wood, animal and vegetable waste and geothermal energy sources were also utilized for TPES. As for other types of RES, wood utilization amounted to 4.730 MTOE while the amount of animal and vegetable waste that was utilized was 2.953 MTOE and that of geothermal heat was about 0.060 MTOE. There was no contribution from wind and solar energy sources. The share of fossil fuels was 72% in 1980. In the late 1980s, reliance on natural gas rapidly increased, and in the late 2000's, the share of solar and wind energy in TPES increased significantly while that of animal and vegetable started to decline. Animal and vegetable waste were used for residential, commercial and public services before they were replaced by natural gas. The increasing energy demand in all service areas was mostly met by natural gas, which further decreased the share of animal and vegetable waste sources in TPES [1]. Fig. 1 shows source-based variations in TPES [1].

In 2014, Turkey's TPES was 123.937 MTOE, and natural gas had the biggest share, accounting for 32% of the country's TPES. Coal remained a significant energy source and accounted for 29% of the country's TPES. The share of oil, which was the main energy source of Turkey in 1980, decreased to 29% in 2014. The share of RES, including hydro, decreased from 28% in 1980 to 10% in 2014. Hydro provided 3% of TPES, and other RES accounted for 7% of the country's TPES [1]. Nuclear energy had no share in TPES. The aggregate share of fossil fuels in TPES was 90% in 2014. Turkey's domestic production in TPES amounted to 17.358 MTOE in 1980 and increased to 31.049 MTOE in 2014. Despite this increase, however, Turkey has difficulties in meeting its rising energy demand through domestic sources.

It is predicted that Turkey's total primary energy demand will increase to 218 MTOE by the year 2023. It is also estimated that in 2023, coal, natural gas, oil, hydro, nuclear and other energy sources will respectively meet 37%, 23%, 26%, 4%, 4% and 6% of the total primary energy demand [39,40].

Considering the case of realization of these forecasts for 2023, source-based variations in TPES for the years 1980, 2014 and 2023 are given in Fig. 2 [1,39,40].

As shown in Fig. 2, the share of coal in TPES has increased considerably over a span of 35 years; it rose from 21.30% in 1980 to 28.66% in 2014.

In 1980, 12% of the TPES came from domestic lignite, and approximately 9% of it came from hard coal, of which 78% was sourced domestically. By 2014, while domestic lignite sources still constituted 12% of the TPES, the share of hard coal had increased to 17%, of which 6% was sourced domestically.

The share of oil products in TPES has decreased over a span of 35 years encompassing the years from 1980 to 2014. While the share of oil products was 50.15% in 1980, this rate came down to 29.00% in 2014. Meanwhile, the share of natural gas in TPES increased significantly within the same period. The share of natural gas went down from 0.07% in 1980 to %32.45 in 2014. As for the share of hydro sources, from 3.06% in 1980, it slightly decreased to 2.82% by the year 2014 [1]. The share of other RES (geothermal, wind, biomass, wood, waste from animals and plants) in TPES decreased during the same period. While the share of non-hydro RES amounted to 24.27% in 1980, this share went down to 7.00% by 2014. According to 2023 energy source distribution predictions, the share of natural gas will decrease and nuclear energy will be added to the energy portfolio of the country.

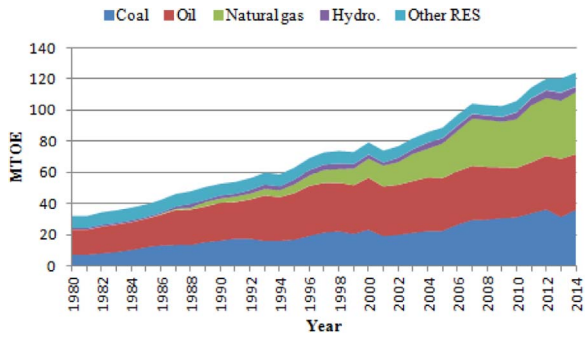

Fig. 1. Source-based variations in TPES for Turkey over the period of 1980–2014.

Turkey imports almost all of its oil and natural gas, both of which have an important share in TPES. The country can produce only a very limited amount of these two sources. In 2005, it produced 896 million Sm^3 of natural gas and imported 26.571 billion Sm^3 of it. In 2013, the volume of production decreased to 562 Sm^3, and the imported amount, which was 45.269 billion Sm^3, almost doubled compared to that in 2005 [41–44].

In the late 1980s, the utilization of natural gas rapidly increased because of its relatively low cost and widespread public perception of it as an environmentally friendly energy source. It is estimated that this increase will continue in future years [45–48].

The amount of crude oil produced in Turkey is limited. In 2004, 2.40 million tons of crude oil was produced in Turkey, while 23.91 million tons of crude oil was imported. In 2014, 2.45 million tons of crude oil was produced, yet in this year the amount of imported crude oil decreased to 17.48 million tons [44,49,50].

The current energy policy of Turkey includes plans to enhance natural gas production operations, find new countries and routes for sources, and increase the importation of Liquefied Natural Gas (LNG). Turkey is aiming to increase the share of domestic sources in TPES to 35% by the end of 2018. Within this scope, the volume of oil and natural gas production, which was 91,200 bbl/d in 2014, is expected to go up to 121,600 bbl/day in 2018, including the production outside the country. The rate at which domestic and outside of the country oil production met consumption was 12.8% in 2013, and the target for 2019 is 13.6% [51,52].

Turkey's unearthed coal reserves, which were 8 billion tonnes, have reached 14.8 billion tonnes thanks to the introduction of new techniques and discovery of new coal sites [53]. The government aims to utilize all the existing domestic lignite and hard coal potential by 2023 [51].

3. Utilization of primary energy sources for electricity generation

Fossil fuels are the main sources of energy used in electricity generation in Turkey. In 2014, 79% of its electricity was generated through fossil fuels. FFPP currently account for 60% of Turkey's installed power, while imported coal plants make up 8.7% of it [1]. Turkey is heavily reliant on natural gas imports, particularly in its electric power sector. There is a general consensus that this trend is unlikely to change and most of the electric energy demand will continue to be met by natural gas in 2023 [41].

16% of total electricity produced in 2014 was generated using domestic coal (40,222 GWh) [54] while 21% was generated through the use of RES. 78% of electricity generation through RES took place using hydropower, which has been the dominant energy source in Turkey for a long time. At present, non-hydro RES make up 4.9% of the total electricity generation. Installed HPPs currently make up 34% of the total installed power. Apart from hydro, wind is another important source whose share in Turkey's power generation is constantly increasing. It has also been observed that geothermal energy has reached a noticeable amount of installed power (404.9 MW). Furthermore, unlicensed solar power plants of 40.2 MW power had been installed by 2014 [6].

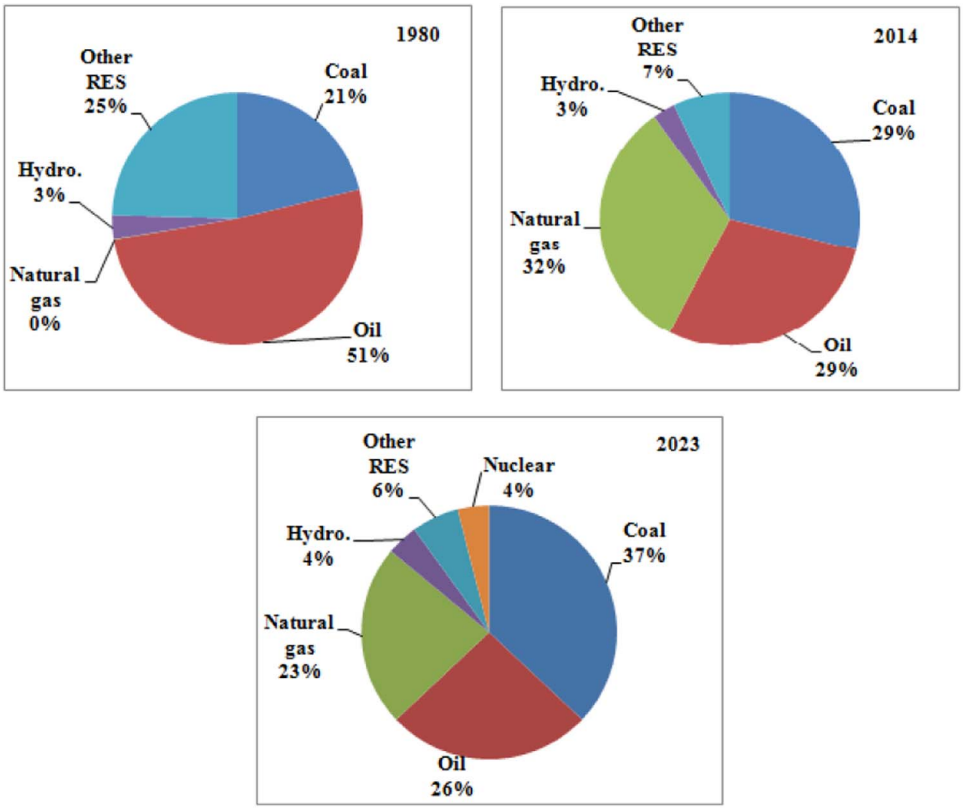

Fig. 2. Source-based variations in TPES for the years 1980, 2014 and 2023.

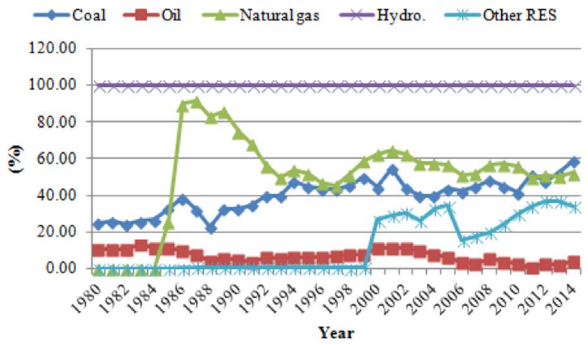

Fig. 3. Utilization of primary energy sources for electricity generation.

The ratio of coal utilized for electricity generation has increased in the last 35 years. While this share was 24.87% in 1980, it rose to 58.79% by 2014. In the same period, the share of oil in electricity generation dramatically decreased. While the ratio of oil utilized for electricity generation was 10.44% in 1980, it fell to 3.84% by 2014. On the other hand, as mentioned above, the ratio of natural gas utilized for electricity generation considerably increased in this period. Natural gas was not utilized at all for electricity generation in 1980, but by 2014, its share was as high as 52.15%. Utilization of non-hydro RES (wind, solar power, wood, and waste from animals and plants) for electricity generation increased during this period. Non-hydro RES, which were not utilized for electricity generation in 1980, were being used at a rate of 33.95% by 2014 [1]. Fig. 3 shows variations in the utilization of primary energy sources for electricity generation [1].

4. Greenhouse gas emissions and variations in coal utilization rates

Global warming that has arisen from GHG emissions occupy an important place in the world agenda as one of the most alarming issues to be overcome. CO_2 emissions account for 77% of the global GHG emissions. It is estimated that 57% of CO_2 emissions are caused by the use of fossil fuels [55].

GHG emissions caused by power generation account for two thirds of the global GHG emissions, which means that energy sector plays a major role in climate change [56]. It is predicted that the goal of limiting global warming to 2 °C will be possible on condition that the pledged measures are taken against climate change. Realization of the proposed changes is expected to result in an increase of more than 40% in the global demand for electric energy by 2030. In return, the rising trend for GHG emissions is expected to either discontinue or be reversed. If the pledges made by the nations are kept, CO_2 emissions caused by electricity generation, which were 518 gCO_2/kWh in 2014, will decrease to 382 gCO_2/kWh by 2030. Carbon density in accordance with primary energy consumption was 2.36 tCO2 /TOE in 2014, but with the intended measures it can be expected to decrease to 2.14 tCO2 /TOE in 2030 [56].

Even though Turkey's CO_2 emission per capita is below the world average, there is a considerable increase in emissions. While CO_2 emission rate across the world increased by 0.5% between 2013 and 2014, a 7.30% increase was seen in Turkey in the same period. With this rate of increase, Turkey has the seventh highest rate of increase in CO_2 emissions among all countries. Yet the average CO_2 emission per capita is 4.9 t/year in the world, compared to 4.5 t of CO_2 per capita in Turkey at present [57–59].

The rate of GHG emission per capita was 3.77 t CO_2-eqv in 1990 in Turkey, yet this rate increased to 6.08 t CO_2-eqv by 2014. In comparison to 1990, total GHG emissions of the country increased by 125% in 2014, reaching 467.6 Mt CO2-eqv. It should be noted that 72.5% of these emissions were from the energy sector [60].

The share of coal in the primary energy supply of the world is 29%. Its share in global electric energy generation is 40%. It is estimated that the use of coal is responsible for 44% of CO_2 emissions from fossil fuels and 72% of CO_2 emissions from electricity and heat generation. Given that it is the chief source of GHG emissions, energy generated from coal

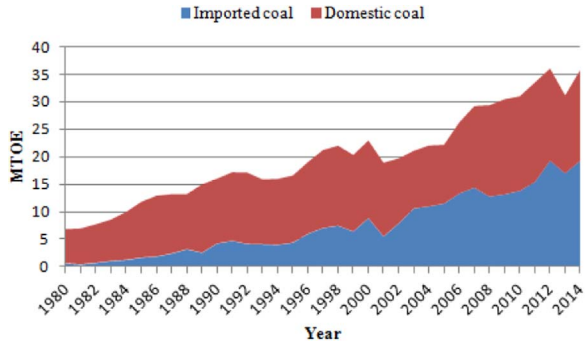

Fig. 4. Variations of coal utilization in TPES between 1980–2014.

can be considered as the primary cause of climate change [61].

Coal utilization for energy generation has been increasing in Turkey. The amount of coal within TPES was 6.794 MTOE in 1980 and it had increased to 35.75 MTOE by 2014. The ratio of imported coal in total amount of coal in Turkey's TPES increased in the 35-year period spanning 1980–2014. While this rate was 8.47% in 1980, it rose to 53.71% by 2014. The shares of coal types in TPES between 1980–2014 are given in Fig. 4 [1].

It can be seen that the rate of hard coal and lignite utilization for electricity generation has increased from 1980 to 2014. The share of hard coal utilization was 16.54% in 1980, and it increased to 42.78% by 2014. As for lignite utilization, the share was 30.38% in 1980 and increased to 79.95% by 2014 [1].

Almost all of the coal imported by Turkey is hard coal, and the amount imported has increased in the past three decades while the share of imported coal was 22.29% in 1980, this increased to 94.47% by 2014 [1].

The use of imported coal and the costs associated with it have been on the rise in Turkey. Imported coal, accounting for almost 9% of the electricity generation of Turkey by 2014, cost 2 billion-dollars in 2006 and the costs reached 4.6 billion-dollars in 2012. Russia, the country supplying most of Turkey's natural gas, is also the main supplier of coal imports [62].

Turkey's energy policy aims to give priority to the use of domestic energy resources for electricity generation. For this reason, Turkish government plans to tap into all existing domestic coal reserves for electricity generation by the year 2023 [22]

This policy ignores the alarmingly rapid increase in Turkey's GHG emissions. Keeping coal at the heart of the country's energy policy and promoting the construction of new coal power plants will lead to even higher emissions. It is estimated that the plants expected to be in operation in the near future will lead to an additional GHG emissions of 400 million tonnes. Government incentives for coal have been preventing RES from adequately competing with coal [61]. The proposed changes in the electric market law that are to be discussed in the parliament soon are intended to enable TETAŞ (Turkish Electricity Trade and Contracting Corporation) to buy most of the electricity from domestic coal power plants via yearly bidding [63]. Yenigün and Schlissel [64] state that with this proposed regulation, electricity from domestic lignite coal will be bought at a price higher than the market value of the same amount of electric energy. If the consumers are made to pay for this cost, this will result in an increase in the market price of electricity. Taking into consideration all the negative effects of using coal, this paper argues that energy policies should be revisited with an increased emphasis on RES in order to mitigate GHG emissions as well as achieve self-suffiency.

5. Renewable energy

Renewables generate nearly 23% of the world's electricity, and it is estimated that this share will climb to 30% by 2030 [65]. These sources are projected to be the fastest growing energy sources in the coming years, and the cost of energy generation through renewables is expected to keep its decreasing trend. The pledges made in the Paris Climate Change Conference promote widespread adoption of RES [66]. Despite low oil and gas prices, decreasing costs of renewables and supportive environmental policies have led to a surge in renewable energy deployment. Global renewable energy capacity increased by 8.3% during 2015, which is the highest annual growth rate ever recorded, and total capacity reached 1.985 TW [67].

There has been considerable progress in the field of RES in the European Union (EU) for which Turkey is a candidate country. In EU-28, renewable energy is targeted to account for 20% of total consumption by the year 2020. RES, which made up 8.3% of energy consumption in 2004, has been being utilized more in recent years, concomitant with the decrease in the use of fossil fuel. Accordingly, RES accounted for 15% of the energy consumption in 2013 in the EU-28 countries. In the same year, RES utilization in electricity generation in the EU increased by 177% compared to 1990, thus accounting for 26% of total electricity generation [68].

The share of RES in TPES and electricity generation varies depending on the period subject to analysis. This variation mostly arises from the large share of hydroelectric power generation in RES. Hydro sources account for approximately 80% of power generation through RES in Turkey, and depending on the amount of precipitation there are variations in power generation through hydro sources. In order to provide a comparison with other countries, this article involves an analysis of the variations in the share of RES between 2004–2013 in Turkey. The share of RES in gross final consumption of energy rose significantly between 2004–2013 in Turkey. While energy from RES accounted for 5.9% of gross final consumption of energy in 2004, this share increased by 60.8% and reached 9.5% by 2013. In the same period, the share of RES in gross electricity consumption slightly decreased. While RES accounted for 30.8% of electricity generation in 2004, this rate decreased to 28.9% by 2013. An important development in this period is that, although there has been a decrease in the share of hydro in electricity generation, the share of non-hydro RES has increased. Hydro accounted for 30.6% of electricity generation in 2004, but this went down to 24.7% in 2013 [2]. In order to provide a comparison, the rates of primary energy consumption and electric energy generation in Turkey and some EU countries are given in Table 1 [1,2,68].

With new investments on the way, electricity generation through domestic coal is targeted to reach 60 TWh/year by the end of 2019. The government is making plans to introduce three NPPs in order to diversify Turkey's electricity supply portfolio. According to these plans, nuclear energy is expected to be the source of at least 5% of the country's electricity generation by 2020 [15,39,69]. As a consequence of increased efforts to utilize domestic lignite and hard coal reserves, all the while increasing the use of RES, it is estimated that natural gas use

Table 1
Renewable energy rates in some EU countries and Turkey.

Country	Share of energy from renewable sources in gross final consumption of energy (%)			Share of electricity from renewable sources in gross electricity consumption (%)		
	2004	2013	Change 2013 over 2004	2004	2013	Change 2013 over 2004
Sweden	38.7	52.1	34.6	51.2	61.8	20.7
Austria	22.7	32.6	43.6	61.9	68.1	10.0
Italy	5.6	16.7	198.2	16.1	31.3	94.4
Spain	8.3	15.4	85.5	19.0	36.4	91.6
Germany	5.8	12.4	113.8	9.4	25.6	172.3
Luxembourg	0.9	3.6	300.0	2.8	5.3	89.3
Turkey	5.9	9.5	60.8	30.8	28.9	−6.2

in electricity generation will be reduced to below 30% in total electricity generation by 2023 [15,39,69].

Turkey has pledged to generate at least 30% of its electricity from RES by 2023. Until then, it is anticipated that the country's yearly electricity demand will reach 424 TWh. To realise the targets, the government aims to add 61,000 MW of renewable installed power, to generate approximately 159 TWh by the year 2023. The composition of this amount is expected to be as follows: 34 GW (91.80 GWh) of hydro, 20 GW (50.00 TWh) of wind, 5 GW (8.00 TWh) of solar, 1 GW (5.10 TWh) of geothermal, and 1 GW (4.53 TWh) of biomass energy [15,39,69].

In case of successful realization of the Vision 2023 energy targets, the distribution of source types in total energy generation is expected to be as follows based on their current share: 38% RES, 14% domestic coal, 5% nuclear energy, 30% natural gas, %2 oil based products. Also, it is highly likely that there will be around 47.69 TWh of energy supply shortage. This supply shortage would amount to almost 11% of the total electricity generation and would probably be met by imported coal or natural gas. Considering the increasing share of imported coal in electricity generation and Turkey's plan to reduce its dependency on natural gas for electricity generation, we predict that this gap will most likely be filled by imported coal. According to the energy policy targets and assumptions, the source-based variations in gross electricity generation of Turkey for the years 1980, 2014, and 2023 are given in Fig. 5 [2,3,15,39,52,69].

In 1980, 26% of electricity was generated from coal, 22% coming from domestic lignite and 4% from hard coal, 78% of which was sourced domestically. By 2014, the share of lignite coal was 14%, while the share of hard coal had increased to 15%. However, only 6% of this hard coal was sourced domestically. In the projection for 2023, assuming all the domestic coal sources will be utilized, the share of domestic coal within the total amount of coal used is expected to be around 14%.

The 1980 electricity generation mix included hydro, domestic lignite, hard coal, oil, and a limited amount of animal and plant waste. In 2014, almost half of the electricity was generated from natural gas. Compared to 1980, the share of energy generation from oil products decreased in 2014. The 2014 energy mix also included geothermal, solar, wind, and biomass energy. Despite the diversification of RES, self-sufficiency of the country in electricity generation decreased to 37% [1–3].

Table 2
RES potentials, installed power and 2023 forecasts.

RES	Economic potential (MW)	Installed power (MW)/2015	Installed power (MW)/2023 target
Hydropower	36,000	25,649	34,000
Wind	48,000	4283	20,000
Solar	50,000	226	5000
Geothermal	2000	614	1000
Biomass	2000	346	1,000
Total	138,000	31,118	61000

Drawing on the country's current energy policy figures and dynamics, it can be said that Turkey's self-sufficiency in electricity generation is expected to rise to 52% by 2023. By that time, nuclear energy will have been included in the energy mix. The share of geothermal, solar, wind, and biomass sources in electricity generation is expected to increase, while the share of natural gas is expected to decrease.

Assumptions and estimations regarding the shares of oil products and imported coal in Turkey's electricity generation mix in 2023 were made to ensure diversification of energy supply. Under the present conditions, when we examine the value of currently installed power of RES, it seems that attaining 2023 RES targets is a highly challenging venture. The assumptions regarding the share of oil products and imported coal were based on this concern. Turkey's RES potentials by source, installed power (licensed and unlicensed), and 2023 forecasts are given in Table 2 [3,6,15,16,39,70].

Turkey has a total of 240,165 GWh/yr electricity generation potential from RES, and the total economic potential from RES is 138,000 MW as shown in Table 2 [15,16]. Regarding hydropower, it is estimated that Turkey's economic potential is 36,000 MW (with an annual average generation potential of 144,000 GWh/yr), 25,649 MW of which had been installed by the end of November 2015. The government aims to reach 34,000 MW installed power by the year 2023 [3,6,15,39]. As regards wind, the economic potential is estimated to be 48,000 MW (with an annual average generation potential of

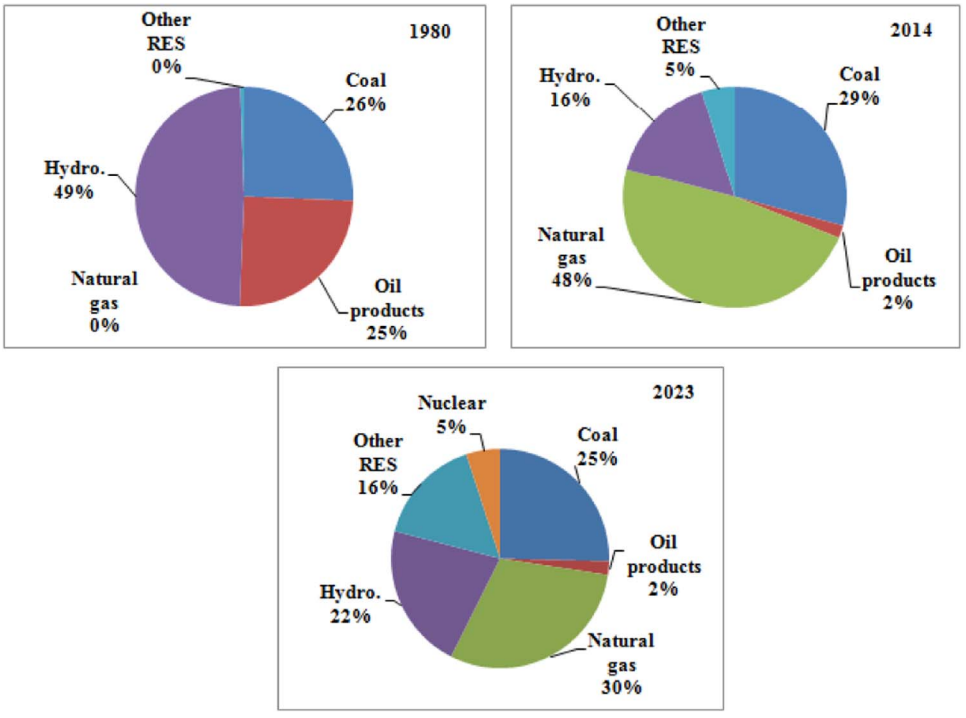

Fig. 5. Source-based variations in electricity generation for the years 1980, 2014 and 2023.

60,000 GWh/yr), 4283 MW of which had already been installed by the end of November 2015. The government aims to attain 20,000 MW installed power by 2023 [3,6,15,39]. As for solar power, the economic potential is estimated to be 50,000 MW (with an annual average generation potential of 7500 GWh/yr), but only 226 MW had been installed by November 2015, based on unlicensed electricity generation. The government aims to have 3000 MW of installed solar power by 2023 [3,6,15,39,70]. So far, unlicensed electricity generation based on solar power turned out to be the most attractive type: 331 out of 360 projects that have so far been commissioned are solar power based. The total capacity of 360 unlicensed RES plants is 284.282 MW, while the total capacity of 331 solar plants is 225.957 MW [70]. The Energy Market Regulatory Authority (EMRA) received pre-license applications for solar energy licences of 600 MW designated capacity, and the Turkish Electricity Transmission Company (TEİAŞ) held 6 bids to choose companies that will undertake on-grid solar power generation in 27 provinces and 38 cities of Turkey. In total bids, 43 selected investors acquired the pre-licenses by offering the highest contribution fee per MW (grid connection fee) that will be paid to TEIAŞ in three annual installments following the preliminary acceptance of the plants. There is only one licensed solar plant with 8 MW capacity in Turkey [71–73]. In geothermal energy, economic potential is estimated to be 2000 W (with an annual average generation potential of 14,665 GWh/yr), and 614 MW was installed by November 2015. The government aims to achieve 1000 MW installed power by the year 2023 [3,6,15,16,39]. As regards biomass, the economic potential is estimated to be 2000 W (with an annual average generation potential of 14,000 GWh/yr), and 346 MW of this was installed by November 2015. The government aims to achieve 1000 MW installed power by 2023 [3,6,15,39].

Despite having substantial RES potential, Turkey has not exploited its potential sufficiently. Taking the economic potential of RES into account, the utilization rates of RES are as follows:

Turkey has utilized 71.20% of its economic hydropower potential.
For wind power, utilization rate is 8.92%.
For solar power, utilization rate is 0.452%
For geothermal, utilization rate is 30.70%
For biomass, utilization rate is 17.30% [3,6,15,16,39,70].

By the end of November 2015, Turkey attained about 51% of its 2023 RES target. with 31,118 MW installed power. According to 2023 RES targets by source types, attainment rates based on RES types are as follows:

Turkey has attained 75.40% of its 2023 target in hydro.
For wind power, attainment rate is 21.41%.
For solar power, attainment rate is 4.52%
For geothermal, attainment rate is 61.40%
For biomass, attainment rate is 34.60% [3,6,15,16,39,70].

In accordance with the Turkish electrical energy generation capacity projection, new projects that are granted licences are underway and expected to become operational between 2015 and 2018. Two different scenarios (Scenario 1 and Scenario 2) are discussed in the EMRA progress report. According to these scenarios, wind power projects with 881 MW (scenario 1) and 751 MW capacities (scenario 2) are expected to be commissioned until the year 2018. Biomass plants with 9 MW (scenario 1) and 14 MW (scenario 2) are expected to be commissioned. For geothermal plants, 251 MW of capacity is expected to be commissioned in both scenarios. For hydropower, 4130 MW (scenario 1) and 4, 573 MW (scenario 2) capacity is expected to be commissioned until the end of 2018 [5].

Even though Turkey has a significant RES potential, this potential is not being utilized effectively and the country has been rather slow in approaching its 2023 energy policy targets. It is clear that a number of limitations have caused Turkey's failure in utilizing its RES potential. Reasons for these limitations can be listed as follows:

- Investors experience difficulties in obtaining licenses. It is a lengthy process that requires the investors to apply to many institutions,
- Expropriation processes take a long time,
- High contribution fees are paid at the license competitions,
- Turkey failed to benefit from other countries' experiences,
- Turkey has been very late in establishing its Renewable Energy Support Mechanism (RESM) compared to some EU countries,
- Low tariffs under RESM compared to the EU countries,
- Administrative hurdles,
- Obstacles to grid access,
- Lack of knowledge and training in RES [13,15,18,74].

There has been an increase in the number of wind and HPPs benefiting from the RESM in recent years, and almost all the biomass and geothermal power plants benefit from the RESM.

In recent years, the revenue gap between the Market Exchange Price (MEP) average and the RESM prices has increased in favor of the RESM prices. The reason for the rise in the revenue obtained within the RESM is the upsurge in the foreign exchange rates. There are fluctuations in foreign exchange rates in Turkey due to the political instability in the country and its conflict-ridden surrounding, which in turn adversely affects the predictability of prices.

6. Energy self-sufficiency and self-sufficiency in electricity generation

While Turkey's TPES significantly increased, from 31.973 MTOE in 1980 to 123.937 MTOE in 2014, the country's self-sufficiency in energy decreased. The rate of self-sufficiency was %54.42 in 1980. However, this rate went down to %25.05 by 2014. Due to the rapidly increasing demand for electricity during the above-mentioned period, a higher percentage of primary energy sources started to be used to generate electricity. In 1980, 7.26% of the TPES was used to generate electricity and this rate increased to 22.24% by 2014. Fig. 6 shows the variations in the rate of self-sufficiency and in the proportion of primary energy sources utilized for electricity generation [1].

The cause of the decrease in self-sufficiency is the sharp increase in energy consumption and a simultaneous decrease in power generation through domestic energy sources and RES. Fig. 7 shows data on TPES and power generation through domestic sources and RES between 1980 and −2014 [1].

As seen in Fig. 7, the decision to meet the increasing energy demand by imported natural gas and imported hard coal is part of the reason why domestic energy sources and RES have remained underutilized and insufficient in keeping up with the high surge in TPES. From 1980–2014, the share of imported hard coal in the total coal supply increased sharply from 8.47% to 54%.

By 2014, the share of coal within the total energy supply was approximately 29%. The limited amount of natural gas that was being produced in 1980 was only used in the industry. It was not used for electricity generation yet. In 2014, the share of natural gas in Turkey's TPES was 32.45%, and its share in electricity generation reached 48%.

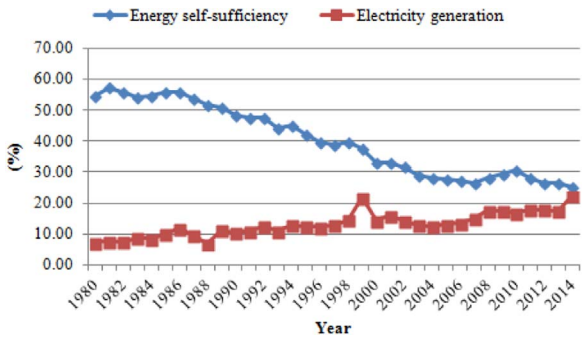

Fig. 6. Variations in the rate of self-sufficiency and in the proportion of primary energy sources utilized for electricity generation from 1980 to 2014.

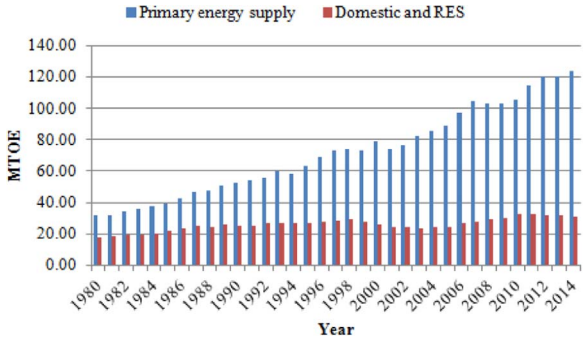

Fig. 7. Variations in TPES and power generation through domestic energy sources and RES between 1980–2014.

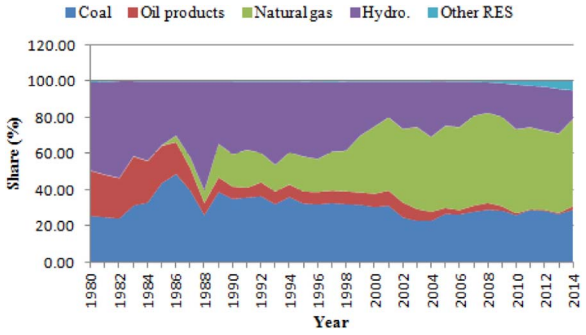

Fig. 8. Source-based variations in gross electricity generation of Turkey over the years 1980–2014.

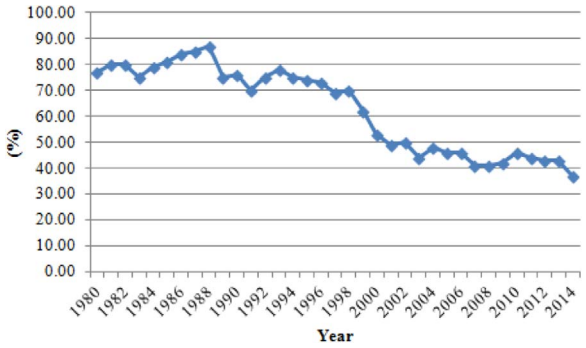

Fig. 9. Self-sufficiency rates in electricity generation between 1980 and 2014.

As regards HPPs, their share in TPES slightly dropped from 3.05% in 1980 to 2.81% in 2014. The share of non-hydro RES in TPES was 24.37% in 1980, mainly consisting of wood, animal manure, and plant waste. Later in the 80 s, the share of these sources decreased due to the marked increase in energy production from coal, oil and hydro sources. The decline in the share of energy obtained from wood and manure for heating changed the energy mix. By 2014, the share of geothermal, wind, solar, and other RES in total energy production had become 7% [1].

In 1980, almost half of electric energy production came from HPPs. The lignite power plants relied 100% on domestic sources and produced 21% of the country's energy supply. Another important energy source was oil, with a share of 25%, as natural gas was not yet utilized for electricity production. The self-suffiency rate in oil production was 15%. The share of hard coal in the energy mix was only 4%, and the self-suffiency rate of its production was 78%. Non-hydro RES were yet being used in production. Between 1980 and 1984 the energy mix did not change, although there were small changes in the shares of energy obtained from different sources. Geothermal energy entered the energy mix in 1984 with a share of 0.07%. Starting in 2009, the installed power of geothermal energy increased, its share in energy generation going up to 0.09%. Turkey started generating electricity from domestic natural gas in 1985, which, however, had a negligible share of 0.017%. The same year, the share of electricity generated from lignite in total production was approximately 42%. Beginning in 1985, the share of natural gas steadily increased while the share of oil started to decrease. In 1987, Turkey started generating electricity from imported natural gas. With a share of 60.25%, electricity generation from HPPs was at its peak in 1988 in the span of 35-year period this study scrutinizes. The year 1989 is significant for the growth in energy generation from natural gas, 95% of which was imported. Its share, which was 18.3% for that year in electric energy production, has been steadily increasing since then. By 1999 natural gas had become the energy source with the highest share in electricity generation in Turkey, reaching 48% in 2014. In 2003, production from hard coal, the self-sufficiency rate of which was 10%, started to rise and reached 15% in 2014. Wind energy was added as a new constituent to the energy mix in 1998, with 55 GWh generation. 2007 saw a significant increase in the installed power of wind, which continued to rise in the subsequent years and reached a share of 3.38% in total electricity generation in 2014. Finally, solar energy entered the energy mix in 2014 with 17 GWh generation. Source-based variations in gross electricity generation of Turkey over the years from 1980 through 2014 are shown in Fig. 8 [1].

Partly as a result of source-based variations in electricity generation, Turkey's self-sufficiency in electricity generation deteriorated from 77% in 1980 to 37% in 2014. The changes in electricity generation self-sufficiency rates between the years 1980 and 2014 are shown in Fig. 9 [1].

Turkey's increasing dependence on imported energy sources resulted in a decline in its economic indicators due the rising expenditures on energy imports. The foreign trade deficit increased from 20.40 billion-dollars in 1996 up to 84.56 billion-dollars in 2014. This rise in the foreign trade deficit occurred in parallel with the increase in energy import costs. While the total export value was 23.22 billion-dollars and the total import value was 43.63 billion-dollars in 1996, within this sum, energy import costs of the country amounted to 5.91 billion-dollars. Thus, energy import costs account for 29% of the total foreign trade. In 2014, the total export value rose to 157.62 billion-dollars and the total import value increased to 242.18 billion-dollars. Within this sum, the share of energy import expenditures was 54.88 billion-dollars. Thus, as of 2014, the energy import expenditures accounted for 65% of the foreign trade deficit. Fig. 10 shows the energy import rates and foreign trade deficits between 1996 and 2014 [75,76].

7. Conclusion and recommendations

Due to its economic growth rate, the consumption of primary energy sources has been increasing in Turkey. As a consequence of the decrease in power generation through domestic energy sources and RES, coupled with a simultaneous increase in the consumption of primary energy sources, Turkey has seen a major decline in its energy self-sufficiency in

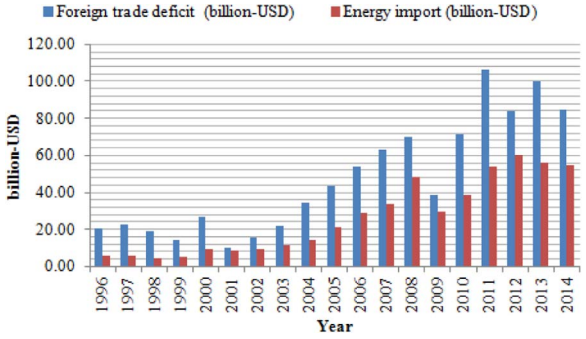

Fig. 10. Energy import rates and foreign trade deficit between 1996 and 2014.

TPES. The country's rate of self-sufficiency decreased from 54.42% in 1980 to 25.05% in 2014. This deterioration in self-sufficiency mainly arises from the increase in the share of imported natural gas and hard coal in TPES. In 2014, average energy self-sufficiency rates in OECD member countries and the EU member states were 80% and 47%, respectively.

As it has been stated above, the self-sufficiency of the country in electricity generation dropped from 77% in 1980 to 37% in 2014. The main reason for this deterioration is increase in the use of imported natural gas and imported hard coal. Except for HPPs, the county's potential for RES has not been sufficiently exploited. The changes in precipitation rates also resulted in a decline in energy generated by HPPs, which has in turn resulted in a higher share of energy produced from imported energy sources.

Fossil fuels provided 72% of TPES and 51% of electricity generation in 1980. By 2014, the share of fossil fuels reached 90% and 79% in TPES and electricity generation, respectively. In case of realization of 2023 energy targets, fossil fuels can be expected to make up 86% of TPES and 57% of electricity generation by then. The share of coal in TPES and electricity generation followed an upward trend together with the increase in the amount of coal imported in the aforementioned 35-year period.

Given the existing energy policy plans, it is clear that the country's dependence on fossil fuels will continue in the future years, which means that the foreign trade deficit partly caused by the high energy import costs is likely to remain. Considering the energy import rates and foreign trade deficit between 1996 and 2014, it can be seen that the share of energy import cost in foreign trade deficit has been steadily increasing.

Fossil fuel dependency and high growth rate also mean that there will be a continued inflation in GHG emissions. The alarming increase in GHG emissions is the main hurdle that the country has to overcome while utilizing its domestic coal reserves. Unfortunately, energy policy emphasis on coal utilization could cause the emissions to further increase in the near future. Taking all this into consideration, coal, be utilized more efficiently and effectively, which means coal-fired plants with highly developed combustion technologies and high cycling efficiencies need to be installed. Establishment of carbon capture and storage plants should be promoted through specific incentive schemes as a long-term transformation policy measure in the energy sector. If Turkey maintains its energy policy centered on coal, for example by providing incentives for coal and building new coal power plants as existing plans suggest, inevitable outcomes of this policy will be an increase in fossil fuel dependency, energy costs, and GHG emissions and a decrease in the competitive power of renewables, Policy emphasis on coal will create an economy and industry that rely on it, which is in the long run likely to result in an increase in coal imports and a concomitant decrease in self-sufficiency.

Turkey does not have sufficient domestic sources of oil and natural gas. However, it can be self-sufficient in terms of electrical energy through the utilization of domestic energy sources and RES and increased emphasis on measures to enhance energy efficiency. It is aimed that by 2023, 30% of electricity generation should be provided by RES. Considering this target and the share of sources planned to be used (22% hydroelectric and 16% other RES), power generation through RES will largely take place through HPPs. In 2023, electricity generation through domestic energy sources and RES (with hydro) is expected to make up 52% of the country's total electricity generation. Considering the targets stated in Turkey's energy policy documents, it is predicted that the country's energy self-sufficiency and the proportion of electricity generation through domestic energy sources and RES will considerably increase by the year 2023.

The analysis of variations in the utilization of TPES for electricity generation reveals that there has been a decrease in the last decades in the proportion of oil used, while a considerable increase is the case in the use of natural gas. Even if the relative proportions have changed, electricity generation through coal has increased in the past three decades. Although there have been fluctuations in the share of electricity generation through domestic energy sources and RES, there has not been a consistent increase. This results from RES-based electricity generation being mostly based on hydro.

From a geopolitical perspective, the desire for being self-sufficient is unarguably at its strongest when it comes to energy. At present, there is a political turmoil in the Middle East. In addition to that, the recent tension between Turkey and Russia has raised uncertainties over the future of Akkuyu NPP. If this tension continues, it may cause delays in the construction of the Akkuyu NPP, which has not yet been granted production license. Public acceptance of NPPs in Turkey is another topic that has to be addressed. Citizens' opinions on the proposed construction of NPP have to be taken into account. Turkey imports about 50% of its natural gas, and any shortfall (either temporary or permanent) in Russian natural gas will endanger the energy supply security of Turkey, given that the country has limited natural gas storage capacity. Energy import dependency leaves the country vulnerable to supply disruptions. These distruptions could be caused by political or commercial disputes and/or infrastructure failures. In order to ensure energy security, despite supply challenges, increasing the deployment of RES plays a crucial role.

As long as fossil fuels dominate the electricity supply system of Turkey, achieving self-sufficiency is highly unlikely. At this point, we suggest that Turkey's rich RES potential could and should play a significant role in achieving a higher rate of self-sufficiency in electricity generation. To reach self-sufficiency and to decrease GHG emissions, utilization of RES should be promoted by using appropriate incentives. Attaining the 2023 RES targets not seem highly probable for Turkey given the current low utilization rates of non-hyro RES, despite the relatively good progress in the expansion of hydro and geothermal.

It seems that hydro will continue to be the predominantly used RES types in Turkey's future. However, the amount of electricity generation through hydro depends on the amount of precipitation, which leads to considerable fluctuations in the amount of electricity generated from year to year. It should also be considered that one of the marked effects of climate change is drought. And, in case of drought in Turkey, a major decrease in power generation through hydro would be inevitable. Therefore, we suggest that the deployment rate of non-hydro RES in Turkey should be increased. In order to achieve this, the barriers to the utilization of Turkey's RES potential, which have been discussed in this article, must be overcome.

In order to decrease dependence on foreign energy sources and foreign trade deficit, Turkish government plans to increase consumption of domestic coal. However, increased consumption will further trigger Turkey's already-rapid growth of GHG emissions. By considering such negative impacts of coal utilization, coal subsidies that keep coal prices artificially low must be curbed. Coal subsidies should be transferred to the development of RES projects. RES incentive mechanisms should be accompanied by other regulatory policies in order to promote the RES deployment rate. Capital subsidy incentive can be complemented with FiT which already exists in Turkey but remains in effective. Putting an effective price on carbon emissions through market-based mechanisms is one of the most effective policy measures to reduce the CO_2 emissions. Voluntary emission trading projects have been implemented in Turkey. Applying carbon taxes on FFPP would create considerable revenue and can be used to incentivize and raise the deployment of RES in Turkey. Carbon tax will build a carbon price, which would in turn allow renewables to compete with fossil fuels more fairly.

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